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X2000 POWER SYSTEM ARCHITECTURE

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ABSTRACT

JPL is starting a new program that targets the exploration of the outer planets in our Solar System. The Advanced Deep Space System Development Program (ADSSDP) is to provide a spacecraft system for a series of missions exploring the outer planets. The first objective of the program is to provide an engineering model of the spacecraft system by the year 2000. The engineering model, dubbed the X2000, is basis for the first series of missions. The program will continue to advance the "state of the art" in spacecraft system development with a new engineering model every three years to benefit the missions that follow.

The X2000 power system must answer the challenge of an outer planets spacecraft by reducing its power, mass and volume envelope. Traditionally, there has been an increasing trend of the percentage of the power system electronics to the total spacecraft mass. With all of the previous technology focus on high-density digital packaging, the power system electronics has not been keeping pace forcing the spacecraft to take a major hit in the power system mass. New technology being developed and validated by the New Millennium Program will aid in the reduction of the power system allocation to meet the total spacecraft mass and volume budget. "l'he new technology in MCM packaging and mixed signal ASICs increase the packaging density of the power system electronics allowing for the integration in to the spacecraft avionics package.

Although new technology has improved the power electronics packaging density, a power system architecture is required that can reduce the requirements on the spacecraft loads. The arch i tecture can reduce the number of power converters on the spacecraft by providing load specific voltages and by increasing capability in de-coupling loads. The architecture also needs the modularity to accommodate multiple missions while maintaining a low recurring cost.

Although the focus has been on shrinking the power system volume and mass, the efficiency and functionality cannot be ignored. Increased efficiency and functionality will only enhance the power systems capability to reduce spacecraft power requirements.

The combination of the New Millennium packaging technology with the X2000 power system architecture produces a product capable of meeting a wide range of mission requirements with a low system recurring cost.

ADSSD PROGRAM OVERVIEW

The ADSSD Program is comprised of three elements:

- Outer Planet Technology (X2000)
- Center for Integrated Space Microsystems (CISM)
- Advanced Radioisotope Power Source Program (ARPS)

The thrust of the program is to deliver a series of spacecraft engineering models to meet the requirements of upcoming outer planet missions. Each delivery is to provide dramatic technology breakthroughs enabling higher levels of integration.

The X2000 element's primary focus is on the spacecraft architecture. The architecture must be the capable of integrating different instruments, propulsion modules, power

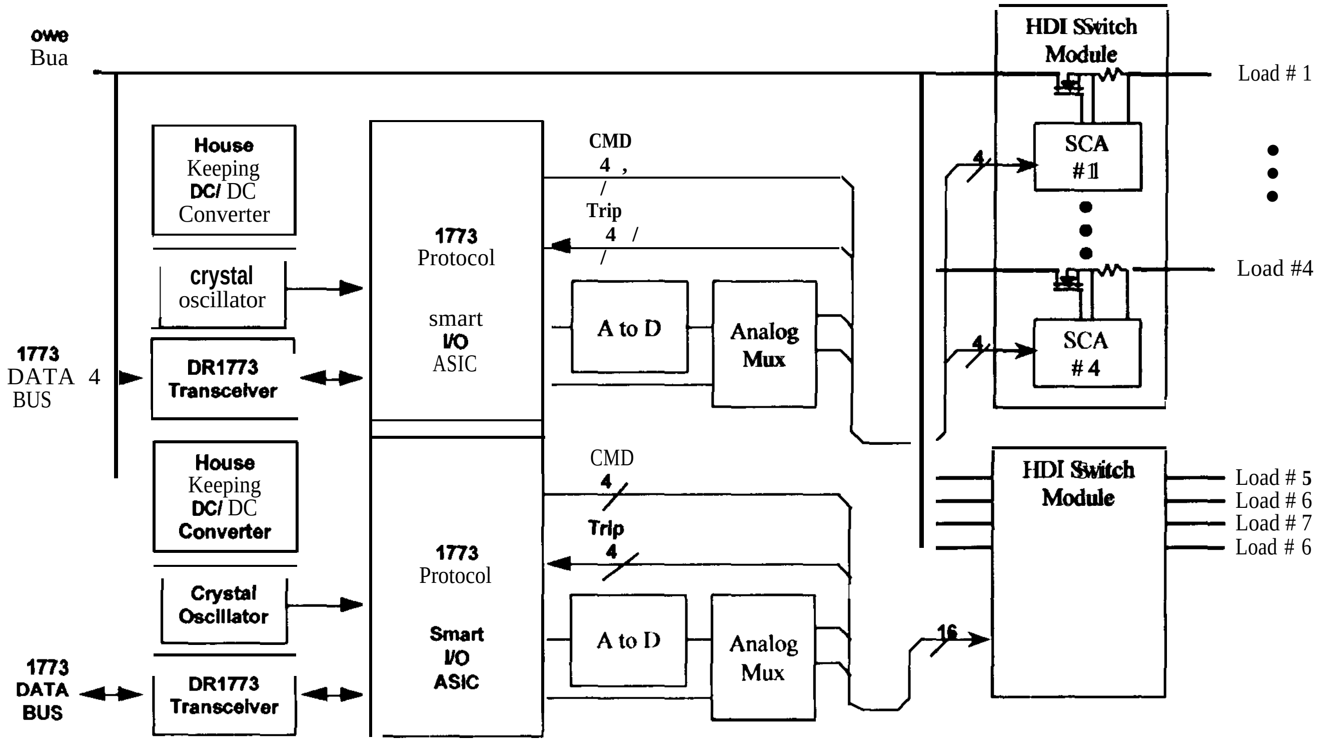

Figure 1: PASM Block Diagram

sources and telecommunication into a multiple mission platform.

The CISM is a center of excellence with the near term focuses on higher levels of integration for spacecraft avionics. CISM will develop new technology enabling this high level of integration with the foresight of future systems on a chip.

The Advanced RPS program will develop a more efficient and robust advanced radioisotope power source meeting the requirements of the future outer planet missions.

KEY TECHNOLOGY DEVELOPMENTS

Technology development has been very limited for many projects. The high non-recurring engineering (NRE) costs and schedule needed for technology development limit what many projects achieve. Additionally, the associated risk prevents many project managers from investing in new technology.

Fortunately, with the formation of CISM for technology development and the New Millennium Program (NMP) for flight validation, many projects can benefit without unnecessary risk.

The goal of CISM and the NMP Microelectronics Integrated Product Development Team (IPDT) is to develop and validate promising new technologies, modular building block designs, and standard interfaces. The IPDT has a number of members from industry, universities, laboratories and NASA with a common goal of producing a roadmap of technology needed for the next generation of spacecraft

One such development is the Power Activation and Switching Module (PASM) which is an experiment slated for the NMP Deep Space I mission. The PASM is a joint development between Lockheed Martin, Boeing and JPL. The goal of the PASM experiment is the flight validation of three promising technologies for the power system electronics. The three technologies are the high voltage mixed signal ASIC, Power High-Density Interconnect (PHDI) packaging, and the dual rate 1773 data bus interface.

The PASM is a power distribution unit with eight power switches and a redundant 1773 interface (figure 1). The switches are current controlled for soft start, current limiting and tripping functions. The command interface to the switches is via a 1773 remote terminal.

The high voltage mixed signal ASIC technology is used for the Switch Control ASIC (SCA) inside the PHDI Switch Module. The SCA is being fabricated on the Harris Radiation Hardened SiGate (RSG) process. This process is scheduled to be QML-V qualified in June 1997. The process was selected for the high breakdown voltage capability of tbe transistors. The total dose radiation level is 300 Krad.

The SCA provides the control function for the power switch. The ASIC contains the digital command and telemetry interface, current control loop, charge pump and level shifting functions (figure 2). The switch is capable of switching from O to 40 V and up to 3 A steady state. Analog current and voltage signals are provided for telemetry. The high voltage process enables the wide range of input voltage to the switch.

The PHDI switch module was design by Lockheed Martin Missiles and Space utilizing the GE technology. The PHDI packaging technology combines the mixed signal ASIC, power MOSFET and discrete components of four switches in a single package. The PHDI packaging technology enables high-density

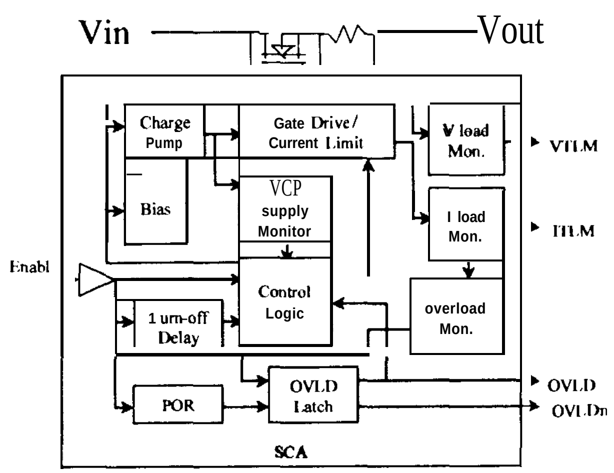

Figure 2: PHDI Power Switch

packaging for power applications. The technology has been previously used for low power digital applications. The technology is providing a factor of four improvement in packaging density over the current state of the art for power switches and is very promising for other functions such as power conversion, shunt regulation and valve drivers.

The Dual Rate 1773 data bus is very promising for the power system due to the isolation of the fiber optic interface. The isolation is a great advantage within the power system to simplify the grounding tree.

The 1773 interface, designed by Boeing, includes the transceiver and the Smart 1/0 protocol ASIC. The Smart I/O ASIC provides a remote terminal to the 1773 data bus.

The PASM is one element in a new integrated power system. The technology validated in the PASM will help the power system architecture to meet the goals of the X2000 program.

POWER SYSTEM GOALS

The following is a list of goals for power system which relate directly to the goals of ADSSDP:

- Multiple-mission architecture
- Increased power management
- High end to end system efficiency

To meet the goal of a multiple-mission architecture, the power system electronics must be a modular, scaleable design with standard interfaces.

The architecture of the power system needs to be partitioned in modules that can be changed depending on the mission requirements. Partitioning the design such that only a single module is affected by either different source, energy storage technology or unique load can reduce the cost of a multiple mission platform.

The power system architecture must utilize this philosophy without sacrificing the capability for design optimization. This requires a combination of MCM packaging with accessible surface mount packaging. With intelligent partitioning of the power system functions, a modular design can evolve with the capability for late changes and minor optimization.

Functions that are common throughout the power system like power switching, pulse width modulation and the command interface, can be incorporated in mixed signal ASICs or MCMS with little concern for future modification. These functions are considered the core building blocks for the power system.

Certain functions that are either load specific or mission specific need accessible packaging. One option for this accessible packaging is discrete components on the surface of either the MCM module, flex print or standard circuit board. Functions such as input filters, voltage regulation, and trip levels, need access to increase the overall power system optimization.

Another goal of the power system is to provide more power management capability enabling missions with very low power source requirements. Power is a limited system resource particularly for outer planet missions where generating power becomes more elusive.

More system visibility in the form of telemetry and power switching enables the system to improve the management capability. By increasing the number of power switches and telemetry channels, the system has more options for accomplishing the mission requirements within the allocated power.

Improving the overall end to end system efficiency is always a goal for the power system. By providing load-specified voltages, the power system can greatly reduce the number of power converters on the spacecraft. Power converters, which can maintain a high efficiency over a wide load range, will greatly enhance the flexibility of the architecture.

The system efficiency can be increased as long as the loads accept that the power system will provide the voltages needed eliminating the need for their dedicated power converter. The objective is to try to achieve a single stage of power conversion from the power source to the end user that can also be shared.

POWER SYSTEM ARCHITECTURE

The X2000 power system architecture (figure 3) was conceived to meet these goals. It is scalable and expandable for different mission power levels and redundancy requirements. It provides a high level of insight into the status of the power system and individual loads, and it uses the highest efficiency components available.

The power system architecture consists of unique functional modules which can be opt i mi zed for a specific power source, energy storage technology or load requirement.

The Power Control module provides the main interface with the power source. The primary function is to regulate the power bus voltage at the peak power operating point of the source. Power Control also provides all of the fault protection and telemetry for the power bus. Although the power system is capable of block redundancy, only one shunt regulator will control the power bus and the other is a cold spare. The power bus is protected from all possible shorts.

The Battery Control module provides the charge and discharge control function for the power system. The module design changes depending the chemistry of the battery or if another technology such as ultra-capacitors or flywheels are used.

The Power Distribution module provides the custom load interface. Each module can be configured with custom magnetics and discrete components to provide the load

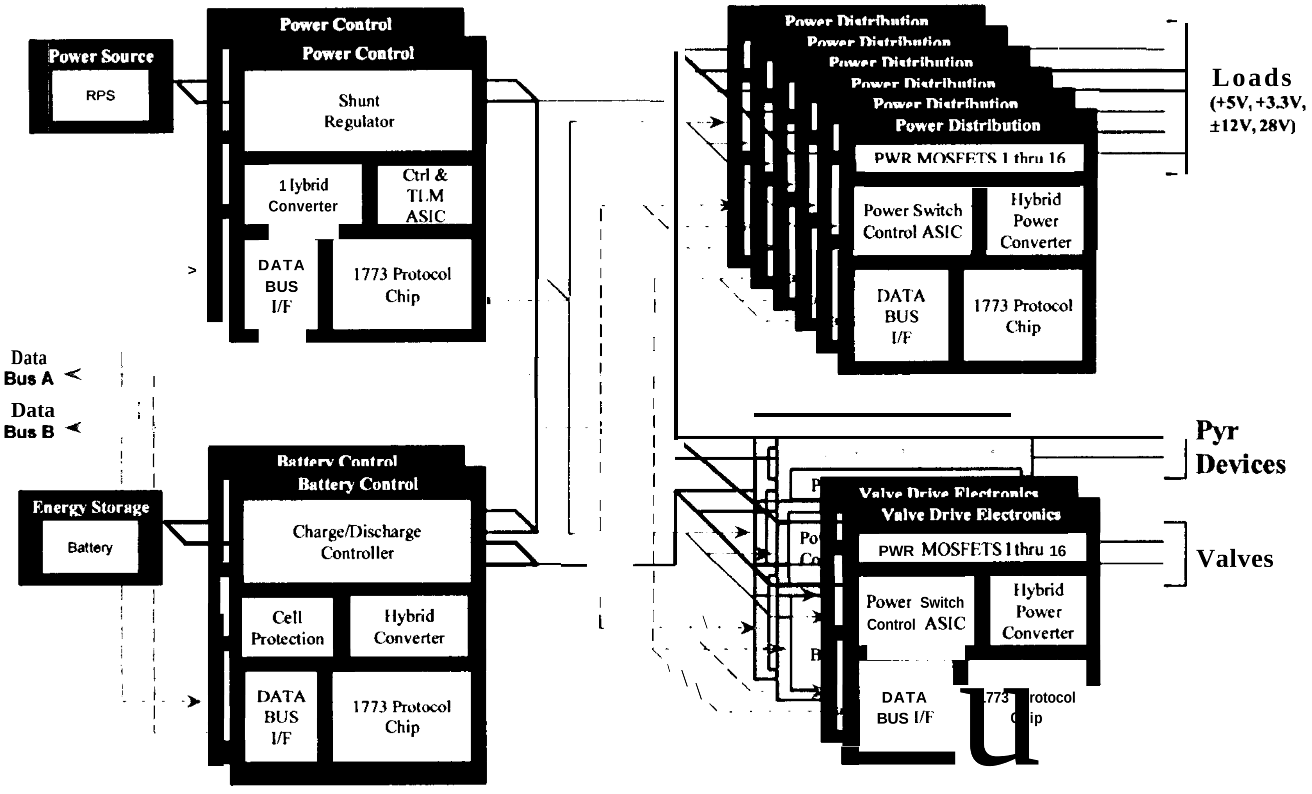

Figure 3: X2000 Power System Block Diagram

specified voltage and power quality. Each interface is protected by a power switch and is commanded via the data bus interface.

The **Valve Drive Electronics module provides the** power and command interface to the valves on the spacecraft. The module can be directly command by the engineering data on the spacecraft. The energy required for the transition of the valve is provided either by centralized or internal energy storage. The purpose of the module is to de-couple the actuation of the valves from the system.

The Pyro Drive Electronics module provides the interface the pyro devices with a similar approach as the Valve Drive Electronics. The drive electronics can be changed depending on the type of initiator used for that mission.

Each power system module has the same standard engineering data bus interface which enables the spacecraft computer direct access to each module. The test and integration costs decrease due to having an industry standard interface combined with increased visibility into each module during system level testing.

The fault protection improves by removing an internal power system command bus that can fail and disable the whole string. With the direct data bus interface, a single failure can disable only one module. Cross strapping is another advantage of direct access to the spacecraft engineering bus. 'I'he data system has a cross-string module enabling either flight computer to usc both data buses.

SOURCE

The power source for the X2000 has some extraordinary mission requirements. Since the mission requirements range from 0.6 AU to 30 AU, **there are a limited number of sources that can be considered. Several different** sources and technologies are being investigated that can provide 90 W of power at 30 AU.

Regardless of the power source selection, the power system architecture needs to accommodate different source requirements from the missions with little impact on the system,

POWER CONTROL

Power control will provide the power bus regulation, fault protection and telemetry. It consists of a shunt regulator, power converter, command interface and undervoltage detector.

The shunt regulator can be optimized to provide bus regulation at the peak output power of the power source. The shunt regulator uses a majority-voted control circuit and several series redundant power stages to reduce internal dissipation and to be single fault tolerant. The number of power stages will depend on the maximum power dissipation capability for the MCM package.

The shunt regulator control circuit can be implemented with multiple chips or a single partitioned mixed signal ASIC. The power stages are packaged in the MCM with the compensation network in accessible discrete components on the surface.

Power Control provides power bus fault protection with a two level undervoltage detector. The first level of protection

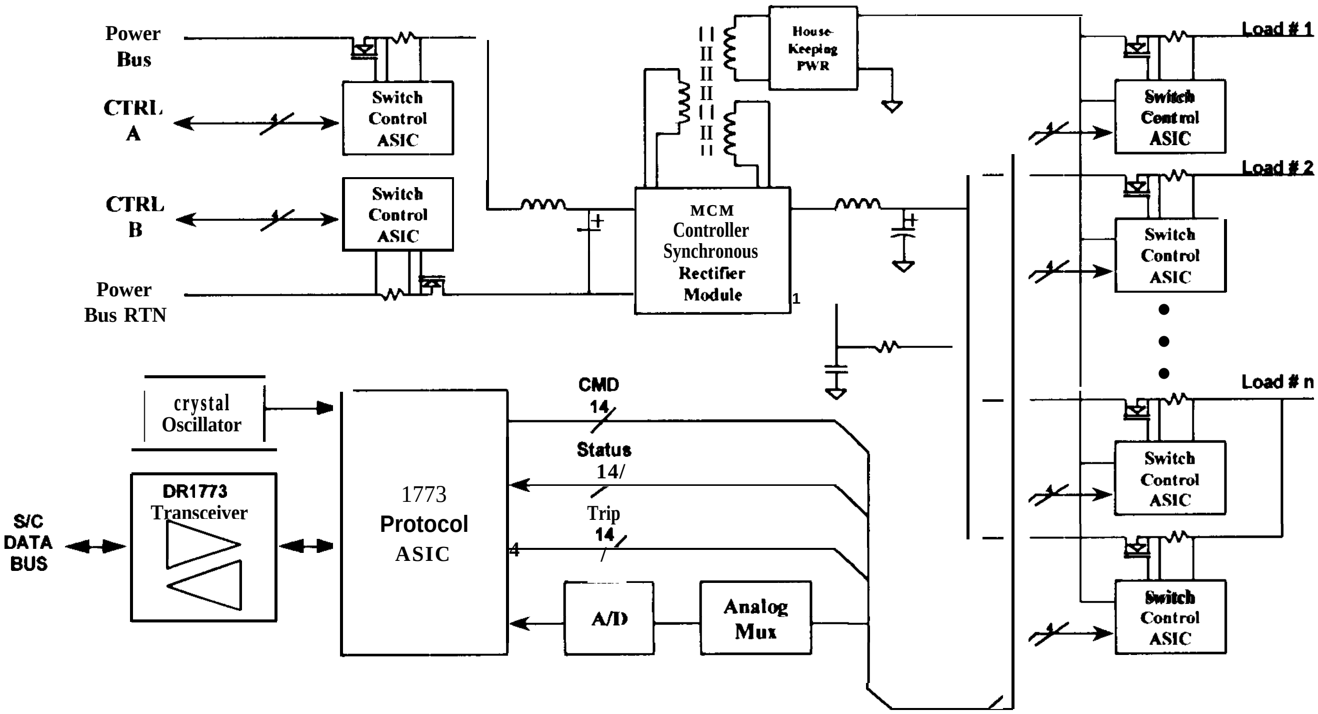

Figure 4: Power Distribution Module Block Diagram

notifies the data system of the loss of power margin. A discrete signal option is available for autonomously load-shedding non-critical loads.

The second level of protection is for a severe bus fault or deep under-voltage. The immediate response is to load-shed via the primary side of the power converters for the non-critical subsystems. The second response is to interrupt the data system and trigger a fault protection response.

Power control will provide the command interface between the spacecraft data bus and the primary side switches for all of the Power Distribution, VDE and PDE modules. Cross strapping is bandied with a digital "OR" function in the switch command path.

BATTERY CONTROL

The Battery Control module is dedicated to controlling the charge and discharge cycle required by the battery. The module contains the charge and discharge circuits, individual cell protection circuits, and the standard command interface.

The design of the charge and discharge circuit depends on the type and configuration of the battery. The circuit is capable of providing constant current and constant voltage control during the charge cycle.

A direct connection to the battery is available for the high transient loads such as pyro initiators and valves. The connection de-couples the high transient loads from the power bus.

The command interface provides visibility into the charge circuitry and telemetry for the battery. The charging circuit can be disabled via command to prevent oscillations between the redundant control circuits in the two Battery Control modules. One module is in control of the battery while the second is a cold spare.

POWER DISTRIBUTION

The Power Distribution module provides power conversion, load switching, telemetry, and fault protection, Each module is designed with a set of discrete components accessible for customization to specific load requirements. The number of modules will depend on the number of loads and the total power of the spacecraft.

The power converter converts the power bus voltage to the load specified voltages. The converter consists of an integrated synchronous rectifier MCM with a discrete power transformer, control circuit compensation, input filter and output filter. Access to the main transformer allows for design optimization to a specific line voltage determined by power control. This allows the system to achieve its maximum efficiency at the peak power operating voltage of the source.

The synchronous rectifier MCM contains all of the switching functions of a DC to DC converter. The package includes the PWM controller, power MOSFETS and drive circuits. The power converter switching frequency can be synchronized from 50 to 200 kHz.

The primary output of the converter is the specified voltage with the highest load. This output has the advantage of a synchronous rectifier which provides higher efficiency at a high load current (O to 10 A up to 50 W), The voltage range of the primary output is 2.5 to 12 VDC. The output regulation is 1%. The overall efficiency of the power converter with a single output is greater than 90% for an output power range of 8 to 30W. The primary output is part of the main control loop of the